

Uses of Linear Polarization as a Probe of Extrasolar Planet Atmospheres

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Abstract. We point out some advantages of making observations of extrasolar planets in linearly polarized (LP) light. Older cool stars have quite low levels ($\sim 10^{-4}$ to 10^{-5}) of fractional LP, while extrasolar planets can have relatively high fractional LP (~ 0.1). Observations in LP light can therefore significantly enhance contrast between the planet and its parent star. Data on LP as a function of planetary orbital phase can be used to diagnose the properties (e.g., composition, size, and shape) of the scatterers in the planetary atmosphere. We discuss the feasibility of LP observations of extrasolar planets.

1. Introduction

An important “next step” in the field of extrasolar planet research will be to characterize their atmospheres. The close-in extrasolar giant planets (CEGPs) will be the first targets; indeed, the tentative detection of Na I in HD 209458b has been reported (Charbonneau et al. 2002). Old cool stars (like most known CEGP hosts) all have very small fractional linear polarization (LP; e.g., Leroy 1993). At the same time, LP measurements are quite sensitive to the properties of scatterers in a planetary atmosphere, and the LP (as a fraction of the planet’s total reflected light) can be significant (e.g., Seager, Whitney & Sasselov 2000 [=SWS]). Thus, LP observations of exoplanets can potentially greatly reduce the star-planet contrast and yield useful data on CEGP atmospheres.

2. Linear Polarization Models for Stars and Exoplanets

Since observations will be of the exoplanet-parent star system, it is important to estimate the LP from the host star as well. In the absence of dust disks, LP from cool older stars is dominated by the “magnetic intensification” effect from optically thick lines in a magnetic field (Leroy 1962). This magnetic LP has distinctive wavelength and rotational phase properties (Huovelin & Saar 1991; Saar & Huovelin 1993). We use the models of Saar & Huovelin (1993) together

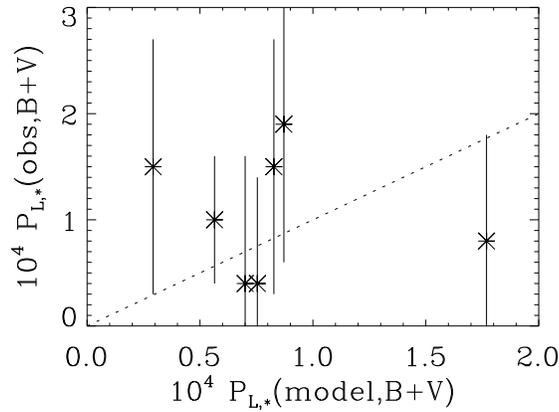


Figure 1. Broadband linear polarization P_L (in the summed B and V bands) from Leroy (1993) compared with our model (based on Saar & Huovelin 1993); the dashed line gives $P_L(\text{observed}) = P_L(\text{model})$.

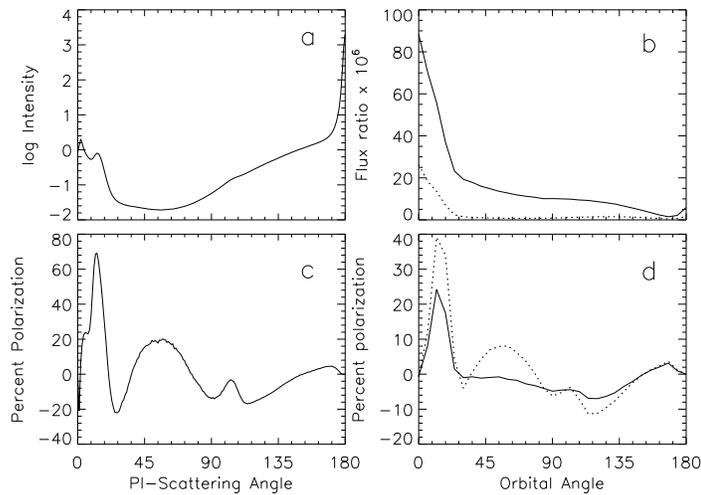


Figure 2. Single scattering phase function (a) and LP probability function (c) input into the Monte-Carlo scattering simulation (SWS). The resulting white light phase function (b) and % LP (d) are shown for the highly scattering fiducial model (solid) and an “absorptive” model with suppressed multiple scattering (dashed). Note that the LP curves (d) preserve the input particle LP properties (c) - even when multiple scattering is high - much better than the light curve (b) preserves the scattering phase function (a).

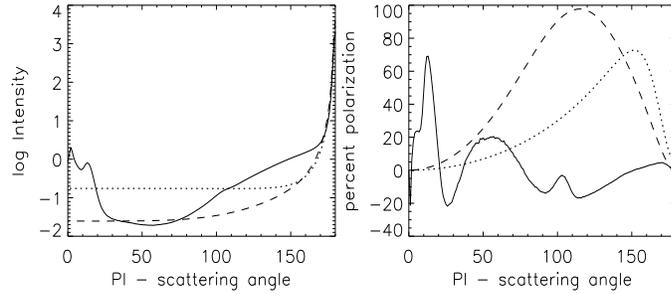


Figure 3. Single scattering phase function (left) and LP probability function (right) for three compositions: MgSiO_3 (solid), Fe (dotted) and Al_2O_3 (dashed). LP is more sensitive to composition: most of the distinctive features in the scattering phase function (left) are at quite low relative intensities.

with active region area estimates from Saar (1996) to estimate the maximum broadband LP (BLP) for selected CEGP host stars. Results are in agreement (within the large observational errors) with observed values from Leroy (1993; Fig. 1); typically, BLP from the host star is on the order of 10^{-4} .

We model the planetary BLP as in SWS. Our fiducial model CEGP is $a=0.05$ AU from its star, with a radius of $R_P = 1.34R_J$, and a gravity $\log g = 3.2$. It is covered by a uniform MgSiO_3 cloud, two pressure scale heights thick, with a log-normal particle size distribution having mean radii of $5 \mu\text{m}$ and $\sigma = 1.5 \mu\text{m}$. The associated scattering phase and LP probability functions are given in Figure 2. For comparison, we also computed the same functions for Fe and Al_2O_3 particles (Fig. 3) and a Rayleigh scattering model (Fig. 4). Figure 2 also shows results of the Monte-Carlo scattering simulation (see SWS for details), the light, and the LP phase curves. These results show LP measurements can better discriminate atmospheric properties than the light curve for several reasons:

- The light curve largely reflects geometric (% illumination) effects (Fig. 2b), while for fractional LP (the ratio of polarized to white light), these effects cancel out (Fig. 2d).
- Multiple scattering smooths the light curve, blurring features distinctive to particular particles (Fig. 2b). The LP curve, which is dominated by single scattering, is much less affected in this regard (Fig. 2d).
- LP measurements are inherently more sensitive to the composition (e.g., Fig. 3), size, and shape of particles than the light curve.

3. Feasibility and Discussion

LP observations of CEGPs will be quite difficult; our fiducial model suggests LP of $\sim 20 - 40\%$ of the reflected CEGP light at best (Fig. 2d). But considerable diagnostic information is gained for this extra detection difficulty, and the contrast between star and planet is improved (in the V band) from $I(\text{CEGP})/I(\text{star})$

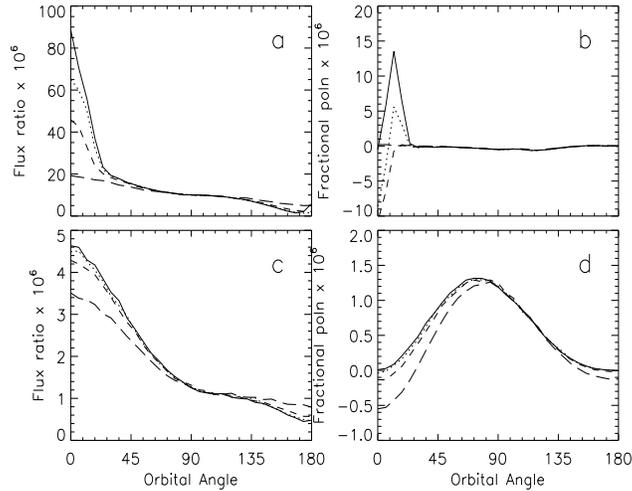


Figure 4. Light curves and LP curves (as a fraction of *total* system light) for the fiducial model (a and b) and a Rayleigh scattering model (c and d). The Rayleigh scattering amplitude is reduced here due to K I absorption; in the blue it is ~ 4 times larger. Once again, model differences are clearer in LP than in white light.

$\sim 5 \times 10^{-5}$ (Fig. 2b) to $P_L(\text{CEGP})/P_L(\text{star}) \sim (\text{few} \times 10^{-6})/(\text{few} \times 10^{-4}) \sim 10^{-2}$, i.e., a factor of ~ 200 . The contrast improvement, and differential nature of the LP measurement, should aid detection at these low flux levels.

Detection could be carried out by BLP polarimetry: searching for a weak (few % of the total) P_L signal phased to the planet's orbital period. This method would work best in systems which are not tidally locked (e.g., *v* And). Another method would be to obtain LP spectra and use some multi-line method to detect the reflected, Doppler shifted spectrum (e.g., Collier-Cameron et al. 1999). The two spectra will be quite distinctive: the star will display an LP spectrum with lines characteristic of those in strong magnetic fields (i.e., Stokes Q and U profiles), while the planet will display a reflected (and linearly polarized in the process) spectrum of the star, and thus appear as a copy of the *unpolarized* stellar spectrum (Stokes I). The striking difference between the two superposed spectra should aid the identification of the exoplanet's signature. Sensitive polarimeters and LP-capable spectrographs on large telescopes may make such observations feasible in the near future.

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The Poster Session